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CARBON FLOWS AND ECONOMIC EVALUATION OF MITIGATION OPTIONS IN TANZANIA'S FOREST SECTOR

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Abstract—This paper presents estimates of the rate of forest use, deforestation and forest degradation, as well as the corresponding carbon flows, in the Tanzanian forest sector. It is estimated that the country lost 525,000 ha of forests in 1990, with associated committed emissions of 31.5 Mt carbon (MtC), and 7.05 MtC of committed carbon sequestration. The paper then describes the possible response options in the forest sector to mitigate GHG emissions, and evaluates the most stable subset of these—i.e. forest conservation, woodfuel plantations and agroforestry. The conservation options were found to cost an average of U.S.$1.27 per tonne of carbon (tC) conserved. Five options for fuelwood plantations and agroforestry, with two different ownership regimes were evaluated. Each one of the options gives a positive net present value at low rates of discount, ranging from U.S.$1.06 to 3.4/tC of avoided emissions at 0% discount rate. At 10% discount, the eucalyptus and maize option has a highest PNV of U.S.$1.73/tC, and the government plantation gives a negative PNV (loss) of U.S.$0.13 tC sequestered. The options with a private/community type of ownership scheme fared better than government run options. This conclusion also held true when ranking the options by the BRAC indicator, with the government fuelwood plantation ranked the lowest, and the private agroforestry option of eucalyptus and corn performing best. The mitigation options evaluated here show that the forest sector in Tanzania has one of the most cost-effective GHG mitigation opportunities in the world, and they are within the developmental aspirations of the country.

Keywords—Tanzania; forest sector; carbon emissions and sequestration; mitigation options; economic evaluation

1. INTRODUCTION

1.1. *Background*

Tanzania is signatory to the Framework Convention on Climate Change (FCCC), which is an international policy and legal instrument culminating from the United Nations Conference on Environment and Development (UNCED) process. The FCCC was signed at the Rio summit in 1992 and became international law upon ratification by the requisite number of signatories in 1994. This instrument recognizes the assertions of the Intergovernmental Panel on Climate Change (IPCC) on the likely adverse impact on the global climate arising from human activities which lead to the atmospheric accumulation of greenhouse gases (GHGs), especially carbon dioxide. The main culprit anthropogenic activities are combustion of fossil fuels and land-use changes. The FCCC requires the signatories to undertake various measures consistent with reduction of the danger to the global climate, beginning with the assessment of each country's contribution to the problem and the outlining and evaluation of possible mitigation measures which can be undertaken individually or in concert with other signatories.

Most developing countries like Tanzania have very low emissions from fossil fuel use, while the land use sectors have relatively higher emissions. Any policies geared to the significant reduction of current and future emissions as well as the sequestration of carbon from the atmosphere should target the land-use sectors. In this paper, we first report an estimate of carbon emissions from the Tanzanian forest sector for the 1990 base year, reached by applying a methodological framework developed at the Lawrence Berkeley Laboratory.[1] Secondly, we identify, describe and undertake an economic evaluation of likely response options in the forestry sector, using a framework proposed by Sathaye and colleagues[25] as reported elsewhere in this issue. In conclusion, we discuss the policy incentives and barriers for implementation of the various response options within the context of the international debate on responsibilities and obligations, given the developmental aspirations of the country.

1.2. *Geography and demography*

Tanzania has a total area estimated at 945,090 km^2, of which 53,480 km^2 is covered by inland water-bodies including parts of the three big East African lakes—Victoria, Tanganyika, and Malawi. The United Republic of Tanzania was formed from a political union of Tanganyika, the mainland, and Zanzibar and Pemba, two islands off the Indian Ocean coast which occupy about 2640 km^2. The country is bordered by Kenya and Uganda to the North, Rwanda, Burundi, Zaire and Zambia to the West, Malawi and Mozambique to the South, and 800 km of coastline with the Indian Ocean to the East.

Most of the country's landscape is on the Central African Plateau between the two folks of the Great Rift Valley, with an altitude of 1000–1500 m above sea level. The relief consists of mountainous highlands in the North-east, rising up to 5895 m above sea level (Mount Kilimanjaro), while the East side consists of a narrow coastal plain. Only half of the country gets precipitation above 750 mm per year. Such areas include the coastal and lake zones, and the southern and northern highlands, which get between 1000 and 1500 mm. The rest of the plateau barely gets adequate rainfall, with 500–1000 mm on average.

The main native factors determining the climate and the resultant vegetation are relief and geographical location. The country has quite diverse and well-drained soils which are, in general, deficient of organic-matter-derived nutrients. The coast, the islands and the high-altitude highlands have a tropical climate, while the rest of the country is mainly subtropical, with large patches of arid area. The rainfall regime is monsoon driven, with December–March being the dry season, and the South-east monsoons governing the long rainy season from March to September. In between the two monsoons, there is a spell of short rains.

The World Development Report 1992[2] estimates a population of 24.5 million in 1990 with a population density of 30.8 per km^2, and a life expectancy at birth of 48 years. About 2.7% of the population lives on the autonomous islands of Zanzibar and Pemba. Of the country's total population, 20% reside in urban and semi-urban areas, a sector which has been growing at an annual rate of 10.5% over the period 1980–1990. The 80% living in the rural areas live in 8700 villages, mainly depending on agriculture and animal husbandry. The total population growth rate has been slowly increasing over the last 25 years, from 2.9% per year in the period 1965–1980 to 3.1% per year for 1980–1990. The population is projected to continue growing at the latter rate for the period 1990–2000, although the early years of the decade show a slight decline in the growth rate. The population growth rate is well above the corresponding average annual real gross national product (GNP–growth rate of 1.8% from 1979–1989. The unfavorable differential between the growth of the population and that of real income will most likely put more pressure on the country's primary resource sectors, with the forest sector being at the forefront of this vulnerability.

2. NATURAL RESOURCES

2.1. *Land use*

Land is by far the most important physical resource for sustenance of the rapidly growing Tanzanian population and for the generation of national income. Land availability is a function of physical attributes as well as the policy and tenurial systems in operation. About 6% of the land area in Tanzania is currently under cultivation, and another 40% is classified as rough grazing land, with most of the rest falling under forests and woodlands.[3] It is further estimated that close to half of the country's land area is arable, which is relatively abundant compared to many developing countries.

The land-use pattern is characterized by a large small-holder sector, with a very low land concentration. The Gini coefficient of land concentration is 0.35, compared to 0.55 for Kenya and 0.64 for Ghana.[4] More than 80% of the agricultural land is in the small-holder sector, and as shown in Table 1, the average land area is slightly less than 5 acres per household. Understanding the land-use patterns is crucial in discerning the rate and extent of conversion of forest land to other uses, and consequently in designing effective policies for sustainable use of land resources.

2.2. *Contribution of the land-based sectors*

The national statistics consider the agricultural sector to include crop production, livestock, fisheries, forestry and wildlife. As shown in Table 2, this sector contributed an increasing share of the gross domestic product

Table 1. Distribution of land holdings in Tanzania in 1980

Size (acres)	Households (%)	Land area (%)	Average size (acres)	Mean Household size	Per capita holding (acres)
0–1	6.6	1.1	0.8	3.5	0.23
1–2	12.3	4.6	1.8	3.5	0.51
2–3	20.5	11.8	2.7	4.4	0.61
3–4	15.0	11.8	3.7	5.1	0.73
4–6	22.5	24.5	5.2	5.6	0.93
6–8	10.9	16.4	7.1	6.7	1.05
8–12	9.4	19.8	10.0	7.6	1.32
12 +	2.8	10.0	16.7	9.9	1.70
Total	100.0	100.0	4.7	5.4	0.87

Source: Collier *et al.*[4]

(GDP) in current prices, estimated at 50.3% of GDP in 1982, rising to 62.7% in 1988 and back to 62.5% in 1991 after a slight decline in the interim. The contribution of the sector to GDP in real prices showed a modest increase from 41.1% in 1982 to 48.4 in 1989, slightly declining to 48.2% in 1991. The increasing importance of the land-based sectors to the national economy is largely a result of the poor performance of the industrial sector as well as disproportional escalation of prices in the agricultural sector. Both these factors have substantial consequences for the use and abuse of land resources in the country.

The contribution of the conventional forest sector to national income using market prices is slightly less than 5%.[5] However, the sector has a large number of attributes, products and services which do not lend themselves to market valuation. Furthermore, its linkages with the other sectors such as the agricultural and energy sectors make forestry indispensable for an economy which is mainly agrarian and rural.

2.3. *Forest resources of Tanzania*

The area classified as forest land is about 42 million ha, close to half the country's land area. Most of the remaining area is rangelands and grasslands, generally referred to as rough grazing lands. As shown in Table 3, the forested area mostly consists of natural *miombo* woodlands, which are sparsely populated with a variety of species, the dominant genera being *Brachestegia* and *Julbernedia*. The *miombo* woodlands have characteristically low stocking, averaging about 50 m^3/ha with an annual biomass increase between 2 and 4 m^3/ha. About 25% of the area shown as *miombo* woodlands is a substantial pre-climax ecosystem known as transition or intermediate woodlands which serve as an important source of woodfuel in the drier parts of the country. The rest of the forest estate consists of a small expanse of closed forests, mangrove forests and human-grown plantations. Although these are more well stocked, and have a high mean annual increment (MAI), their total biomass is small as compared to that in the *miombo* woodlands, which provide the bulk of the country's wood requirements.

2.4. *Deforestation and forest degradation*

The rate at which the forest area is being converted to other land-uses has been increasing with the rapid increase in population which is mainly land dependent. Forest land is converted to agricultural land as well as depleted for production of woodfuel, especially charcoal.[15] Other factors which contribute to deforestation and degradation include logging, overgrazing and forest fires.[16]

Estimates of the deforestation rate in Tanzania have been put forward by various sources, but there has not been a concise study to quantify the rate at which forests are being converted to other land uses or being degraded. The Forest Division has estimated that in the early 1980s, the rate of deforestation was between 300,000 and 400,000 ha/yr.[17] Ahlback[9] puts the figure at about 600,000 ha for the

Table 2. Contribution of agriculture and forestry to GDP

Year	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	Average
%GDP[a]	41.1	43.3	43.8	45.0	46.1	45.8	45.9	48.4	47.8	48.2	45.3
%GDP[b]	50.3	53.7	54.1	58.8	58.9	58.9	62.7	61.7	58.3	62.5	57.8

Source: Tanzania Bureau of Statistics.[5]
[a]In 1976 prices.
[b]In current prices.

Table 3. Summary of forest resources in Tanzania 1990[a]

Forest type	Area ($\times 10^3$ ha)	Total fallow area ($\times 10^3$ ha)[b]	Biomass density (m^3/ha)	MAI (m^3/ha/yr)	Total biomass stocking ($\times 10^6 m^3$)
Miombo woodlands	40,000[c]	4984	50	2–4	2000.0
Closed forests	1400	154	197	5–10	275.8
Mangroves and coastal thickets	100[d]	—	100	4.6	10.0
Other woodlands, shrubs and thickets	179	22	5	0.3–0.7	0.9
Industrial plantations[e]	98	5	350	15–25	17.2
Village[f] plantations	80(135)	6	135	15	1.1
Total	41,857	5171	56	3–4[g]	2305.0

Sources: The biomass data for natural forests is based on the CIDA inventory carried out in the early 1970s covering 4.3 million ha, Temu[6] and Malimbwi *et al.*[7]. The data for plantations is from Makundi,[8] as well as FD management plans for industrial plantations in Tanzania, and Ahlback.[9] The areas under different forest types were obtained from various FD and MLNRT reports, and FAO,[10] MacKinnon and MacKinnon,[11] and Lovett.[12]

[a]Doesn't include trees and perennial crops in agricultural and/or other non-forest land.

[b]Includes short fallow (areas cleared for shifting agriculture) as well as long fallow (cleared areas abandoned for decades which have been re-colonized by some woody secondary vegetation. In both cases, some woody vegetation exists on the site.

[c]Close to half the area of the country. Adjusted for deforestation in the past decade.

[d]80,000 ha on the mainland and 20,000 on the islands.

[e]The biomass stocking for plantations is an average based on a sustainable rotation management scheme (Mbonde *et al.*,[13] Swedeforest Consulting AS[14]).

[f]The recorded area was 115,000 ha by 1988. Extrapolation using the same recorded rate of 10,000 ha per year would give 135,000 ha by the end of 1990. However, reports and discussions on the status of the program conducted with Forest Division officers associated with village afforestation scheme, as well as extensive examination of various district and regional development reports indicate that the woodlot area with adequate stocking could not exceed 80,000 ha by the end of 1990.

[g]Weighted average.

early-to mid-1980s, although this was mainly based on a high estimate of 2 m^3 per capita consumption of woodfuel. The FAO estimates the annual deforestation for the period 1981–1990 at 438,200 ha. Given the fact that the rate has been increasing over the period, this estimate would tend to support a thesis of a high estimate during 1990.

Some of the key elements of the problem of deforestation and environmental degradation in Tanzania follow the classical rural under-development paradigm. With a rapidly increasing population which demands more and more agricultural land for food production as well as for producing more cash crops for a foreign-exchange-hungry economy, given stagnant or declining productivity, there will be a rapid depletion of the forest land. The over-reliance on export crops leads to an agricultural expansion competing with traditional land uses, and consequently to the encroachment on previously forested land. The two decades preceding the base year (1990) saw agricultural land productivity declining at a rate of 1% per year. To meet some of the demand for food and cash-crop production, the area under cultivation has been expanding at an annual rate of 5–6% over the same period. Under existing productivity levels, the area under cultivation will double in less than 20 years, just to meet the food requirements of the country.

Secondly, the energy demand of the population is largely met by using the forest resources for fuel, with charcoal for the urban population and firewood for the rural population. Some of the woodfuel demand is met by biomass obtained during conversion of forests to agricultural land. It is estimated that over 90%

Table 4. Wood production in Tanzania in 1990

Product	Volume ($\times$ 1000 m^3)	% Share	% Change since 1980
Roundwood	34,276		46
Fuel and charcoal	32,240	94.1	45
Industrial	2036	5.9	72
Processed wood[a]	208		53
Sawnwood	156		28
Wood-based panels	15		150
Paper and paperboard[b]	37		∞
Net roundwood trade	—		—

Source: FAO Forest Product Yearbooks.[?]

[a]The processed wood is given in solid volume.

[b]Converted by 1.48 volume weight ratio for pulp. Production began in 1987.

of the country's primary energy is biomass based.[18]

Of the consumption of forest products, charcoal and firewood from the forest area represent 94% of the recorded roundwood removals (Table 4). The table, which is compiled from FAO forest product yearbooks, shows that in the 10 years preceding the base year, there was a substantial increase in the recorded consumption for each category of forest products. Furthermore, anecdotal evidence shows that there is a significant unrecorded harvest used for rural home construction as well as fuelwood. The production of 1.4 m^3 per capita indicated here could be an under-estimate of the consumption because it does not include net imports or illicit harvesting.

In all of the wood product categories, the growth of consumption far exceeds the population growth mentioned earlier. Such a demand for wood product consumption exerts a heavy pressure on the forest sector. Logging and procurement of woodfuel, especially charcoal, lead to degradation and deforestation of significant amounts of existing forests.

Other explanations for causes of deforestation unique to Tanzania lie in the institutional and social definition of property rights, as applied to rural resources. Historically, many communities in Tanzania have been pastoralist, or peasant settlements have been very scattered such that claims to property have not been common. Forest resources have traditionally been treated as common property. The available forest resources posed no constraint to the peasant in Tanzania as long as they were relatively abundant. The increased population gradually puts heavier pressure on this resource as fuel is needed for cooking, fodder is needed for animals, more of the forest is used as pasture, more forest is cleared for crops, wood fuel is needed for drying tea and tobacco mainly for export, and there is the fast growth of the urban markets for energy from wood, each placing a demand on the forest resource.

A number of analyses have tried to treat this problem as one of market failure and proposed a solution consisting of assignment of property rights to various groups, and this is supposed to serve as a remedy to correct for the missing markets or unaccounted social costs. In the peasant context, this would amount to granting peasants property rights to the resources they utilize such that the extraction of the resource also includes the social opportunity cost. Ideally, this should be a sufficient correction. In the absence of these property rights, the resource will continue to be depleted as long as each group retains diverging interests, all dependent on the same resource.

Table 5 gives a summary of the deforestation rates for the main forest types in the country. The term deforestation as applied for the purpose of estimating GHG emissions includes harvesting for forest products, e.g. clear-felling. Selective logging is adjusted for the selection intensity and the area estimated on the basis of clear-felling equivalence.

The summary of deforestation estimates given above was synthesized from reports covering various land-use change activities. Assuming a biofuel consumption of about 1.4 m^3 per capita,[19] we estimate that 227,000 ha of *miombo* woodlands are cleared or depleted strictly for the provision of fuelwood and charcoal. Hagman[20] estimated that in the early 1980s, about 75,000 ha of woodlands were being cleared every year to supply woodfuel to Dar es

Table 5. Deforestation and forest degradation in 1990[a]

Forest type	Annual deforestation ($\times$ 1000 ha)	Rate of loss (% per year)	Fallow area[b] ($\times$ 1000 ha)
Miombo woodlands	488	1.25	112
Closed forests	10	0.71	6
Mangroves and coastal thickets	4	4.00	—
Other woodlands, shrubs and thickets	20	11.12	—[c]
Industrial plantations	2	2.04	1
Village plantations[c]	1	1.25	1
Total	525	1.25	5171

[a]Annual estimates for the late 1980s and early 1990s. The estimates do not include loss of woody vegetation from non-forest land such as perennial crops—rubber, wattle, coconut, etc. Neither do they include loss of trees from agricultural land. As such, the emissions are commensurately underestimated.

[b]Area left fallow annually is estimated as 80% of converted woodlands and 50% of closed forests.

[c]The intermediate woodlands are in various stages of recovery, and may be used for agriculture or left alone for decades. It is, as such, difficult to apportion that part which could become classified as fallow in the same consistency as the other types, where being classified as fallow implies primary forests freshly converted to short or long fallow.

Salaam alone. Given a growth rate of above 10% per year for the urban population, the area needed to supply charcoal and firewood should have doubled by 1990. The total area cleared specifically for woodfuel should provide about a third of the woodfuel requirements for the country. The remainder of the woodfuel is obtained from clearing land for agricultural production, logging residues, lopping and the clearing of the other smaller forest types such as mangroves and closed forests by the proximal inhabitants.

The area deforested for agriculture from *miombo* woodlands in the base year is estimated at 139,000 ha of which 90,000 ha is the figure provided by the Ministry of Agriculture, and that of Lands, Natural Resources and Tourism as the annual average increase in cultivated land between 1985 and 1990, ostensibly from woodlands. The remainder of the land converted to agriculture is the estimated woodland area needed to replace the tobacco lands rendered useless through nematode infestation.[21] The wood from this conversion is mainly used for fuel. Another 22,000 ha from woodlands are estimated to be lost in logging and harvesting for commercial and local construction timber.

Data on clearing land for pasture is relatively scarce. As extrapolated from the TFAP report,[19] the country had an estimated 13 million head of cattle and 10 million goats and sheep by the end of 1990, while the carrying capacity of the grazing lands is estimated at about 20 million stock units. However, land degradation and depletion is mainly a result of the fact that the ungulates are concentrated in a few tsetse-infected areas. These areas are extensively burned annually as a part of customary range management practice. Expansion into new woodlands necessitates the burning and clearing of most woody vegetation to fight the tsetse and the malaria-causing mosquito. We estimate that at least 100,000 ha are annually lost through such practices as well as other forest fires.

The estimates of the deforestation rates of other forest types are based on projections from the FAO[10,22] on closed forests and mangroves, and extrapolation of the figures provided in Ahlback[23] on industrial and fuelwood plantations.

After adjusting the degraded area to a depletion equivalence, we give a conservative estimate of 525,000 ha deforested in Tanzania in 1990. Some of the area included in this estimate would not be termed as deforested by the conventional definition of the term. However, for the purpose of estimating carbon emissions and evaluating response options in the forest sector, all forested areas which loose woody vegetation are considered deforested.

Table 6. Carbon emissions from deforestation in 1990 ($\times 10^6$ tC)[a]

Forest type[b]	Prompt emissions[c]	Delayed emissions	Committed emissions
Closed forests	0.61	1.224	1.834
Miombo woodlands	15.38	13.64	29.02
Mangrove forests	0.212	0.112	0.324
Plantations	0.079	0.231	0.310
Total emissions	16.281	15.207	31.488

[a]Extracted from Makundi and Okiting'ati.[24]

[b]The estimates for closed forests include ground water forests, while those for *miombo* woodlands include intermediate vegetation which mainly comprises transitional bushlands and thickets. The forest plantation figures includes industrial and community woodlots.

[c]Prompt emissions refer to those emitted during the year in question from current deforestation and use. Delayed emissions refer to those which take place in future years from decomposition and oxidation of left-over biomass and forest products. Committed emissions refer to the total amount to be emitted from the current years' deforestation and use. In each case, they include emissions from both vegetation and soil.

2.5. *Carbon emissions and sequestration in forestry*

Deforestation, degradation and the use of forest resources lead to emissions of GHGs such as carbon dioxide, methane and nitrous oxide depending on the conversion mode. In order to evaluate the efficacy of any measure put forth for reducing or stabilizing emissions, one needs to estimate the extent of emissions associated with the deforestation. Table 6 presents a summary of the estimates of carbon emissions in the forest sector of Tanzania in the base year, while Table 7 summarizes the carbon sequestration associated with the land-use changes for the base year. The estimates were obtained by applying the COPATH model to

Table 7. Carbon sequestration in 1990 deforested area ($\times 10^6$ m^3 tC)[a]

Growing forest type	Prompt uptake	Delayed uptake[b]
Plantations	0.162	4.05
Recovering woodlands	0.060	2.40
Community woodlots	0.040	0.60
Total sequestration	0.262	7.05

[a]Estimates do not include sequestration in growing forests which were in place prior to the base year.

[b]Assumes rotation ages of 25, 40 and 15 years for plantations, woodlands and woodlots respectively.

the forest land conversion process in Tanzania.[1] The estimates given here show the extent of the problem in the sector and provide a basis for assessing the impact of any mitigation option involving reducing deforestation, as well as those measures which increase forest/tree cover. The sequestration options may use other figures depending on the species and management/silvicultural regimes being employed for that option.

3. RESPONSE OPTIONS

3.1. *General options in forestry*

In the methodological paper presented in this volume,[25] the mitigation options are classified into those which maintain the stock of carbon and those which expand the existing carbon stock. In practical forestry, the former can be reclassified into forest conservation options and biomass utilization efficiency options, while the latter can be re-classified into forest restocking options and non-forest tree planting options.

Under forest conservation, we include policies and measures such as the establishment of forest reserves for biodiversity of flora and fauna, reserves for recreation, water catchments, soil erosion and landscape stabilization, land reclamation forests, and the protection of the forest against fires and botanical epidemics.

The efficiency improvements in biomass utilization include measures such as investment in new techniques and technologies to increase recovery and waste utilization for fuel or subsidiary wood products. Also under this category are measures to reduce waste during harvesting such as reduced impact logging (RIL).

In a country with such a heavy dependence on biomass as an energy source, the introduction of improved woodstoves would constitute a major response option. The use of wood from renewable sources as biofuel to replace fossil fuels may be an attractive option in countries which use substantial amounts of coal and oil, a situation which is not currently applicable to Tanzania.

Under forest re-stocking, we consider measures such as afforestation of open areas into plantations, reforestation of deforested or degraded areas and enrichment planting to increase stocking of understocked forests.

The non-forest tree planting options include those measures which deal with non-contiguous tree cover such as community woodlots, horticultural crops, and agroforestry systems. Also included are non-timber tree farms e.g. rubber, bamboo, extractives, tannins, etc., and those trees grown but otherwise not classified elsewhere, such as urban forests. Among these options, agroforestry seems to be the most promising in Tanzania.

Although all the above options could be practiced in Tanzania, only a subset of these options are evaluated here due to limitations of data and by deliberate emphasis on those options which may currently be included in forest planning or seem to be attractive on account of possible applicability within the context of existing forest policy.

3.2. *Mitigation policies in Tanzania*

3.2.1. *Forest conservation*. About 25% of the country's total land area is protected for wildlife management and the conservation of ecosystems for biological diversity. A further 13 million ha of the land is classified as forest reserves for production and conservation. Of the 3.8 million ha in the national parks, 2.0 million are classified as reserved forests and woodlands. Table 8 gives a breakdown for wildlife management areas.

Conservation can be considered as a possible mitigation measure on two accounts. First, to maintain the integrity of the currently protected ecosystems, and second to add new areas into the network of protected ecosystems.

Some of the reserved areas are under serious pressure for conversion to other land uses. A third of the area in the national parks has an encroachment problem, while wild fires seriously endanger the Kilimanjaro, Mahale, Gombe and Mikumi national parks.[26] As synthesized from the TFAP report,[19] there is just as much area in game reserves which is threatened with encroachment (13.5%) by pit sawyers, illegal logging, grazing, farming and

Table 8. Conserved areas for wildlife management

Management category	Number of units	Area ($\times 10^6$ ha)	% of total land area
National parks	11	3.8	4.1
Ngorongoro conservation area	1	0.8	0.9
Game reserves	18	9.7	10.4
Game controlled areas	56	9.0	9.6
Total	86	23.3	25.0

Source: Ministry of Lands, Natural Resources and Tourism, TFAP,[26] wildlife management chapter.

peasant settlements. The increasing population pressure and declining soil productivity are likely to exacerbate the encroachment problem. As such, measures to secure the currently conserved areas will reduce the associated carbon emissions as well as increase sequestration as the biomass density increases.

Evaluation of measures to contain this process is not possible without a good description of the specific land use conflict surrounding each one of the affected areas and the economic opportunities available to the proximal population. The direct measures to stem the encroachment involve demarcation, monitoring and enforcement. In the long run, policies have to be instituted to re-direct the non-sustainable use of the land as well as provide some developmental alternatives to the people who are responsible for the encroachment.

An indicator of the cost of maintaining the integrity of the protected areas is the cost incurred to protect various reserves in the country. A summary of annual expenditure for various protection projects covering 922,000 ha shows a wide variation in cost per unit area. This varies from 483 TSh per ha to 11,000 TSh per ha, with a weighted average of 930 TSh per ha, which translates to U.S.\$1.51–34.38 per ha, with an average of U.S.\$2.90 per ha using the 1992 exchange rate used in the cited report (TFAP,[19] Appendix C). However, such figures are misleading due to the fact that in the absence of such expenditure, only a part of the forest would have been deforested or degraded in the short term. It makes more sense to say that such cost is incurred to protect only the vulnerable area, which is much less than the whole forest.

The second set of conservation response options involves the expansion of the areas under conservation. Despite the large areas which are reserved in Tanzania, many habitats are under-represented in the reserved areas network. Following recommendations by various ecosystemologists,[27,11] a set of new areas has been proposed which will add another 6.3% to the current area in the national parks and game reserves. Furthermore, the TFAP report proposed that specific ecosystems, especially the closed forests, are conserved for biodiversity. On top of these critical ecosystems, a few *miombo* woodland protection projects are included, plus a proposal to gazette an extensive area covering 6.7 million ha of *miombo* woodlands across six regions. These targets are analyzed below.

The individual projects for conservation of ecosystems and genetic resources are summarized in Table 9 with the corresponding cost estimates for phased-in implementation stretching from 1990 to 2008, depending on the specific project. We assume that the area would have ultimately been converted to other land uses if conservation had not taken place. This implies that the expansion of the reserves does conserve all the vegetative carbon and the amount of soil carbon which would have been emitted in the absence of the conservation measure. The soil carbon loss is estimated at 15 tC/ha on average for *miombo* woodlands and 24 tC/ha for closed forests, while the vegetative carbon is computed from the basic data as shown in Table 13 in Appendix A.

Despite the uncertainty surrounding the parameters, the conservation option shows a wide variation of costs of conserving carbon. A few unique projects such as Ram and the *miombo* have very high cost per tonne of carbon, while a few like Mounts Meru and Kilimanjaro have very low unit costs. The latter can be explained by the fact that the estimated cost is supplementary to an existing national park or forest reserve. The average unit cost for all proposed extensions of reserves of about U.S.\$ 1.27/tC is comparable to other estimates elsewhere.[25] The cost of gazetting a large woodland area cannot be considered as sufficient to preserve the carbon, but is a necessary first step. To estimate the unit cost, one has to add the annualized cost of protection.

The estimate given in Table 9 is only a partial cost due to the fact that the potential deforesters and forest users would, in the absence of any other measure, be displaced to undertake their activities in other areas not covered by the conservation projects proposed above. However, for this option to be complete, the Government should undertake other policy changes as well as provide opportunities for alternative economic activities which do not drain the forest resources unsustainably. The cost of such measures is not included in the unit cost discussed above, but it could be significant.

Three main factors dictate the type of indicator sought for the conservation option. Firstly, as discussed above, the cost data is incomplete. We have no good estimates of the specific non-carbon benefits accruing to society from the proposed reserve areas. Lastly, the

Table 9. Conservation of ecosystem and genetic resources Unit

Forest type/location	Area (× 1000 ha)	Total cost[a] (× 10^6 Tsh)	Conserved Carbon[b] (MtC)	Unit cost (Tsh/tC)
Rain forests				
1. Uluguru S.	16.45	535	3.186	167.9
2. Ukaguru	4.15	135	0.804	167.9
3. Nguru	11.7	380	2.266	167.7
4. Usambaras	7.7	251	1.491	168.3
5. Mt Meru	15.0	7	2.906	2.4
6. Mt Kilimanjaro	22.0	10	4.261	2.3
7. Iringa	10.0	170	1.886	90.1
8. Rau	0.62	510	0.117	4361.5
9. Rondo	2.5	23	0.471	48.8
10. Pugu/Kimboza	1.885	17	0.163	104.4
11. Uzungwa	15.0	488	2.905	167.9
12. Usagara Mts	13.75	448	2.663	168.2
13. S. Pare	3.325	108	0.644	167.7
14. Rungwe	15.0	315	2.905	108.4
15. Rufiji	20.0	84	1.758	47.8
16. Kiono/Zaraninge	2.0	19	0.173	110.0
17. Mbwewe/Ms'bugwe	7.0	65	0.605	107.5
Sub Total	168.08	3565	29.204	122.1
Miombo *forests*				
18. Mpingo	4.5	510	0.263	1937.3
19. Muhuhu	4.0	141	0.234	602.6
20. Itigi/Same	9.0	510	0.526	968.7
21. *Ex-situ*	0.8	510	0.047	10,897.4
Sub Total	18.3	1671	1.070	1561.7
Total (reserves)	186.38	5236	30.274	190.7
22. Gazetting[c]	6700	714	391.95	1.8
Grand Total	6886.38	5950	422.22	14.1

[a]The exchange rate used in the cost estimates was for 1989, when 1 U.S.$ = 150 Tsh.
[b]Includes all vegetative carbon and that portion of soil carbon which would have been emitted.
[c]Gazetting forest reserves in six *miombo* regions covering 6.7 million ha.

pattern of the avoided deforestation/degradation is largely unknown. For these reasons, computation of the BRAC indicator (benefit of reducing atmospheric carbon)[31] will not provide us with any reliable inference from the conservation option, and as such, we only report the unit cost for each project.

3.2.2. *Woodfuel plantations and agroforestry*. As mentioned earlier it was estimated that more than 94% of roundwood removals from the forest estate are dedicated to firewood and charcoal. About 70% of the deforestation in the country is related to woodfuel provision, i.e. 43% directly and 27% from clearing for agriculture. It follows that any serious consideration of mitigation options in the country should be focused on the bioenergy sector. These options include, but are not limited to, the establishment of woodfuel plantations, the increase of agroforestry practices, and the improvement of the efficiency of charcoal production and woodfuel stoves. These are options which are congruent to the national forest resource management plans and are likely to be implemented regardless of the climate change ramifications. In this paper, we explore woodfuel plantation and agroforestry options under two different ownership regimes. The analysis is here done on a per hectare basis, with the explicit assumption that there is ample land to implement these options in many parts of the country (see Table 3).

The more common woodlot afforestation schemes are those intended to supply wood to rural households. Tanzania has been involved in establishing village woodlots since the 1970s and has accumulated some valuable experience.

Table 10. Eucalyptus woodfuel plantations (costs and revenues, × 10^3 Tsh)

Year	Total costs	Total revenues	MAI (m^3/ha/yr)	Volume hactare (m^3)
0	43			
1	8			
2	3			
3				
4			7.7	31
5			8	40
6			15	90
Total	54	90[a]		90

[a]Based on a price of 1000 Tsh/m^3

Table 11. Woodfuel plantations—financial profitability (costs and revenues, × 10^3 Tsh)

Item	Government project	Government/ farmer partnership
Project life	6	6
Initial investment	43	30
Average recurrent expenditure		
Year 1	8	4
Year 2	3	2
Returns		
1. Poles	176	178
2. Fuelwood	90	90
NPV at 10%		
1. Poles	47	74
2. Fuelwood	−3	24
NPV at 3%		
1. Poles	96	123
2. Fuelwood	24	51
NPV at 0%		
1. Poles	122	149
2. Fuelwood	6	83

Using figures from Appendix B, a financial analysis is undertaken as shown in Tables 10–12. The costs and benefits are then used to compare the net present value of the project with that of a similar project where the labour is provided by the villagers (Table 11).

In these two cases where the objective is to afforest for woodfuel, the projects are profitable at reasonable discount rates. At the higher discount rate of 10%, the project which is commercially run yields a negative net worth. However, both the projects are very profitable when the wood is sold as poles instead of fuelwood. It is noteworthy that if everyone was to supply the market with poles, the price of poles would be depressed and that of fuelwood would rise instead. Furthermore, the multi-product scenario gives the growers some market flexibility. The typical village afforestation project in many cases is a collaboration between the Government (including local government) and the villagers. This is considered as a second alternative.

Given such a high return on a project this long, if uncertainty is not an issue and or is assumed to affect every project similarly, then these results would tend to encourage private investors who want to plant woodfuel for profit. Land law and policy would need to be adjusted to make this a normal investment opportunity, while retaining some public interest in land use.

3.3. *Woodfuel from agro-forestry*

Table 12 summarizes the results of comparing the plantation of woodfuel with the fuelwood component of the other alternatives. These other options are agroforestry projects of varying kinds. The alternative with eucalyptus and maize (corn) is very profitable, especially given its short rotation. A thorough comparison would involve considering three rotations of this option with the other two for the rotations to be

Table 12. Indicators for GHG mitigation woodfuel plantations and agroforestry—private and public (costs and revenues, × 10^3 Tsh)

Item	Government/Fuel plantation[e]	Government/ Community partnership[a]	Eucalyptus and maize[a]	Boundary Gravellia and maize[b,c]	Inter-cropping Gravellia and maize[b,d]
Project life (years)	6	6	6	20	20
Initial investment	43	30	—	—	—
Other costs year 1	8	—	—	—	—
Other costs year 2	3	2	5	4	4
Revenues from fuelwood only	90	90	28	32	39
At 10% NPV	−3	24	11	1	3
At 3% NPV	24	50	13	15	18
At 0% NPV	36	58	23	28	35
Standing fuelwood volume (m³/ha)	90	90	28	39	122
Emitted carbon (tC/ha)	47	47	15	23	73
Discounted uptake at 10%	35	35	11	7	23
Discounted emissions at 10%	−26	−26	−8	0	0.5
NPVC at 10%	9	9	3	7	23
BRAC (10 + 1)	−0.03	0.24	0.33	0.03	0.012
NPV(0)/tC[f]	0.77 (1.71)[f]	1.23 (2.73)	1.53 (3.40)	1.22 (2.71)	0.48 (1.07)
NPV(3)/tC	0.51 (1.13)	1.06 (2.36)	0.87 (1.93)	0.65 (1.44)	0.25 (0.56)
NPV(10)/tC	−0.06 (0.13)	0.51 (1.13)	0.73 (1.62)	0.04 (0.09)	0.04 (0.09)

[a]Expanson factor = 1.2, total factor = 1.3, DM Density = 0.65, CC = 0.52.
[b]4 m spacing = 100 trees per ha.
[c]EF = 1.5, T AG factor = 1.25, DM Density = 0.61, CC = 0.52.
[d]5.5 m × 5.5 m spacing.
[e]Assumes that without the project, the fuelwood would have been obtained from woodlands unsustainably.
[f]The value in brackets is U.S.$ per tonne carbon.

comparable. Although not shown here, the three alternatives were compared as if they ran in perpetuity, and the conclusions remained unchanged. In any case, the three agroforestry options are quite profitable for woodfuel provision despite the fact that the value of the agricultural crop was not included in the analysis. This confirms many other studies which have found agroforestry to be a very worthy activity for meeting both the energy and food requirements of the rural population.

Given the assumption that the fuelwood grown in this option replaces wood which was otherwise being unsustainably obtained from natural woodlands/forests, we calculate the indicators used for ranking each option's proficiency in reducing atmospheric carbon. Using the benefit–cost criteria alone, the woodfuel plantation with public/private partnership seems to be the most attractive at 0, 3, and 10% discount rates. At the 10% discount rate and above, the government owned fuelwood plantation is not profitable, while the boundary and inter-cropping agroforestry options barely break even. This can be explained by the fact that the tree density is lower and the rotation age is comparatively long for the price of the wood. However, it should be remembered that the value of the agricultural crop was not included in this analysis, implying that these options will be immensely profitable if the crop output is accounted for.

At the 10% discount rate, the inter-cropping option shows a significantly higher net present value of sequestered carbon (NPVC), 23 tC per ha, with a BRAC value of 0.012. The eucalyptus and maize option (partnership) has the least NPVC at 10% and the highest BRAC value. To compare these options with the conservation option, one notes that at the 0% discount rate, all the woodlot and agroforestry options have a positive NPV per tonne of avoided carbon emissions. Converted to U.S.$, the five options give a negative cost of avoiding emissions (a benefit) of $1.71, 2.73, 3.4, 2.71 and 1.07 per tC respectively, compared to a positive cost of $1.27 per tC average for conservation options (forest reserves).

4. CONCLUSION

Despite the constraints on the availability and accuracy of data, this paper tries to estimate the rate of deforestation and degradation of the Tanzanian forest resource, including those forests converted to agriculture, pasture, harvesting, forest fires, etc. It is estimated that for the base year, 1990, the country lost 525,000 ha of forest land, and this led to a prompt emission of 16.28 million tonnes of carbon and another 15.21 million tonnes, of which the emission is delayed but certain to occur. This is compared to a prompt sequestration of only 40,000 tonnes and a delayed uptake of 7.05 million tonnes.

The paper then describes the possible response options in the sector and evaluates only a subset of these—conservation, woodlots and agroforestry. Although the former was done with incomplete data, the cost of conserving a unit of carbon was found to be quite low, of the order of U.S.$1.27 per tonne of carbon conserved. We evaluated five options for fuelwood plantations and agroforestry, with two different ownership regimes. Each one of the options gives a positive discounted value for low rates of discount, and the options with private/public ownership fared better. This conclusion also held true when ranking the options by BRAC indicator, with the Government fuelwood plantation ranked the lowest, and the private agroforestry option of Eucalyptus and corn coming out best.

In order to be comprehensive, one would need to evaluate the effectiveness of policies and measures to improve the efficiency of biomass conversion to charcoal as well as the introduction of improved stoves. This was not covered in this study, but has promise as a viable mitigation option in Tanzania. Those options which were evaluated need further assessment as to the possibilities, bottlenecks, financing and institutional requirements for their implementation. Such a study should also address the issue of land availability for any such implementation.

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APPENDIX A. SUMMARY OF THE BASIC DATA FOR THE MAJOR FOREST TYPES

Table A1. Basic data for major forest types

Forest type	Stemwood	Expansion factor	Total/above-ground biomass	Wood density	Carbon content	Carbon density (tC/ha)
Closed forest	197	1.74	1.20	0.75	0.55	169.7
Groundwater forest	168	1.95	1.40	0.69	0.52	164.6
Semi-evergreen	155	1.34	1.14	0.58	0.52	71.4
Savanna woodland	47	1.57	1.25	0.89	0.53	43.5
Intermediate	15	1.50	1.25	0.61	0.50	8.6
Mangrove forest	100	1.23	1.54	0.70	0.55	72.9
Plantation	200	1.20	1.30	0.65	0.48	97.3

Table B1. Production cost for woodfuel plantation, 1993 (450 Tsh = U.S.$1)

Year 0	Cost ($\times 10^3$ Tsh/ha)
Seedlings (1600) at 10 Tsh each	16
Transportation of labour and materials	3
Land preparation	13
Stacking and pitting	7
Planting	4
Sub-total	43
Year 1	1
Beating-up and weeding	8
Year 2	2
Clearing	3
Total direct production cost	54

APPENDIX B. FINANCIAL EVALUATION OF A WOODFUEL PLANTATION

Costs and revenues

The cost estimates used here were estimated from factor inputs obtained from Makundi[8] and Swedeforest Consulting AB,[14] which were then adjusted using the prevailing factor and product prices, assuming a constant labour productivity.

Establishment of one ha of a provenant eucalyptus species (e.g. *E. radiata*, *E. camaldulensis*, *E. meliodora*, etc.) as a woodfuel plantation at a spacing of 2.5 m × 2.5 m requires an initial 1600 seedlings and a few hundred additional seedlings for beating-up, depending on the survival rate of the initial seedlings. The direct production cost per seedling is Tsh 54,000.[26] The rotation age is assumed to be 6 years and the mean annual increment (MAI) is about 15m^3/ha/yr.[23,28]

The production costs for a woodfuel plantation are shown in Table B1. If the farmer provides labour, this cost could be reduced by 50%,[21,26] assuming that his/her opportunity cost is zero or insignificant. In this case, the total direct cost would be reduced to about 30,000 Tsh.

The plantation can be sold as fuelwood at rotation age. The price of fuelwood varies from place to place, ranging from Tsh 400/m^3 to Tsh 1500/m^3. However, the average price, also used in the calculation, is Tsh 1000/m^3.

A hectare can produce about 90m^3 of fuelwood. Alternatively, the plantation can be sold as construction poles. About 1600 poles can be produced per hectare.

The average length of one pole is 5.5m[29] and the price is Tsh 20 per m^3 (about Tsh 1100/pole).